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MOMS- micro-optomechanical systems

MOMS is a recently invented acronym for micro-optomechanical systems. The term refers to miniaturized optomechanical devices or assemblies that are typically formed using micromachining techniques that borrow heavily from the microelectronics industry. The term may be used to distinguish devices and microsystems that combine optical and mechanical functions without the use of internal electronic devices or signals. Systems that use electronic devices as part of the microsystem may be referred to as MOEMS (microelectrooptomechanical systems). In some cases these terms may be used synonymously. A related area is MEMS, (microelectromechanical systems) in which electronic and mechanical functions are combined in a miniature device or system, but not necessarily implementing optical functions. The progress of MOMS technology has been greatly enabled by the simultaneous development of microelectronics and optical fiber-based telecommunications technology. These two technologies have resulted in a large manufacturing and scientific base from which MOMS has been developed.

Although similar in concept to MOEMS technologies, MOMS has unique advantages for some applications that distinguish it. The use of only optical energy and signals gives MOMS an inherent immunity to electromagnetic interference (EMI) that is important for applications in electrically noisy or high voltage environments. The absence of semiconductor electronic devices greatly increases the high temperature tolerance of the system. MOMS devices can be designed to work immersed in liquids, which is of great importance for chemical sensing and biomedical applications. The fact that the power and signal sources can be remotely provided via an optical fiber, allowing the sensor to be passive, is of great utility and reduces the impact of a MOMS sensor on its local environment. MOMS can be used safely in flammable and explosive environments, making them uniquely valuable in the petrochemical industry.

A micromechanical system is able to either function as a sensor or as an actuator. In the former one endeavors to measure a physical parameter with minimum impact on that value from the operation of the sensor and with low sensitivity to other parameters that may be changing. In use as an actuator, one is performing some mechanical work that will either change the local environment or control or enable energy or information to be transported or controlled. MOMS applications have been primarily in sensors utilizing a number of physical phenomena. MOMS sensors consist of some moveable mechanical element that can be detected or measured by optical means. The motion may be coupled to temperature, electrical and magnetic fields, acoustical energy, acceleration, chemical forces on surfaces, etc. Many sensors can be made sensitive to various physical or chemical phenomena by addition of special surfaces or coatings to the mechanical element. The state or position of the mechanical structure can be detected optically by various means. Many sensors use intensity modulation of a light beam. This may be by mechanical interruption of a beam path or by more subtle means, such as defocus or deflection of light to be coupled into an optical fiber. Many sensors use phase modulation as the sensing means. This requires the use of an interferometer to convert phase into a detectable amplitude modulation. The interferometer may be one of several types. Fabry-Perot devices can utilize free-space propagation of beams normal to the mechanical surfaces to detect motion or position of the surfaces. Mach-Zehnder and other designs that require splitting and recombination of light beams are often implemented as guided wave devices in which the light is confined in planar thin film structures. Interferometric detection can be very sensitive, but places additional requirements on the light source and detection electronics. A third mechanism is wavelength, in which a broad spectral source can be spectrally dispersed or filtered. Polarization is also an optical parameter that can be used in some cases. Since many MOMS sensor applications use optical fibers as the sources of power and means of data retrieval, MOMS sensors are often discussed in the context of optical fiber sensors. MOMS can be distinguished from the more mature field of fiber-optic sensing by their use of miniaturized or integrated mechanical structures, formed by micromachining techniques, as the sensor. A MOMS sensor is extrinsic to the optical fiber, as opposed to intrinsic optical fiber sensors, in which the fiber is the sensing device.

MOMS actuator technology is much less developed. The actuation mechanisms that are available to allow light to do mechanical work are few. Photothermal mechanisms allow the conversion of light to heat to power a thermomechanical actuator. Examples of this include expansion of a working fluid or deforming a bimetallic strip through differential thermal expansion. Photoexcitation of semiconductor structures can be used to generate electrostatic and surface charge effects or cause photostriction in piezoelectric materials to impart mechanical force. Light can also produce direct radiation pressure, but the forces are small relative to the light intensity. A system can be powered by light through photovoltaic conversion, but then would not be considered purely optomechanical and classified as a MOEMS device.

The fabrication technologies used for MOMS are all based on the use of microlithography as a means of defining microscopic structures in large quantities and great precision. Microlithography produces a two-dimensional pattern on the surface of the substrate in a resist material that is coated on the substrate surface. The resist will protect some areas from subsequent process steps or act as a barrier that can be removed later as a sacrificial material. The microlithographic processes are then combined with various micromachining processes to define the mechanical structure. The micromachining processes are generally additive, in that material deposited in sequence to build up a structure on a substrate or subtractive in which deposited films on the substrate or the substrate itself are removed to form the structure. The commonly used processes are the same as used for variations of the MEMS fabrication processes with some additional materials choices, due to the need to be compatible with optical functions. Surface micromachining in thin film layers on silicon substrates is the most advanced process in terms of miniaturization, integration and industrial support, as it uses the processes and tools of the silicon integrated circuit industry. The limitations of this process are due to the thin structures that are produced and the weak actuator forces that can be implemented by the thin film structures. Bulk micromachining involves mostly subtractive processes that sculpt the silicon or other substrate to produce simpler, more robust structures that may incorporate thin film membranes on the silicon surface as well. Recent variations of this process use deep reactive ion etching to form these structures with more versatility than can be attained by wet etch processes. These processes may be supplemented by wafer bonding to join structures together that have been processed on separate substrates originally. Another process available is LIGA, a German acronym (for lithographie, galvanoformung und abformtechnik) that refers to the combination of deep x-ray lithography with electroforming of metals and (sometimes) injection molding, to produce mechanical parts that are larger and more robust than the semiconductor fabrication processes. The disadvantage of LIGA is its lower level of integration, with more assembly required for functioning systems. Polymer replication processes, including casting, embossing and injection molding are also applicable to some MOMS fabrication needs. In all these cases, the use of micromachining, which can be performed in high volume, can produce extremely small and precise devices at low cost per device.

Some examples of MOMS technology include optical pressure transducers, microphones or hydrophones that have a thin mechanical membrane that is one surface in a Fabry-Perot interferometer formed by the reflection from the membrane surface and the reflection from the end of the fiber. Other versions have a planar optical waveguide on the surface of a sensitive membrane that is one arm of a two-beam Mach-Zehnder interferometer. Another example is an accelerometer in which a small mass is suspended from flexure attachments to the substrate. Optical fibers are positioned with a small gap in which the moving mass can interrupt the transfer of light from one fiber to another to modulate the light intensity transmitted through the fibers. One of the most well developed MOMS applications is optical sensing of the position of small cantilevers used in scanning tip microscopy processes such as atomic force microscopy. In some versions of these extremely sensitive instruments, a micromachined cantilever or balance mechanism is subject to forces from a sharpened tip on the end of the lever that interacts with the interatomic forces of a surface. The forces bend or tilt the mechanism with displacements of angstroms. The minute bending or tilt can be measured optically by angular change of reflected light from the surface of the beam without perturbing its position.

Micro-optomechanical systems are still in their infancy. As optical fiber communications becomes more pervasive, use of MOMS can be expected to increase as a means of optical sensing and in some cases actuation, for situations in which it provides unique value. Some challenges have to be addressed to further improve the performance, cost and utility of MOMS. Integrating optical and micromechanical functions, that often require different materials and processes, is difficult and limits the sophistication and complexity that can be achieved with MOMS technology. The packaging requirements of MOMS require input and output coupling of optical signals into a package that often needs to be in intimate contact with its environment for the sensor to function, while still protecting the system.

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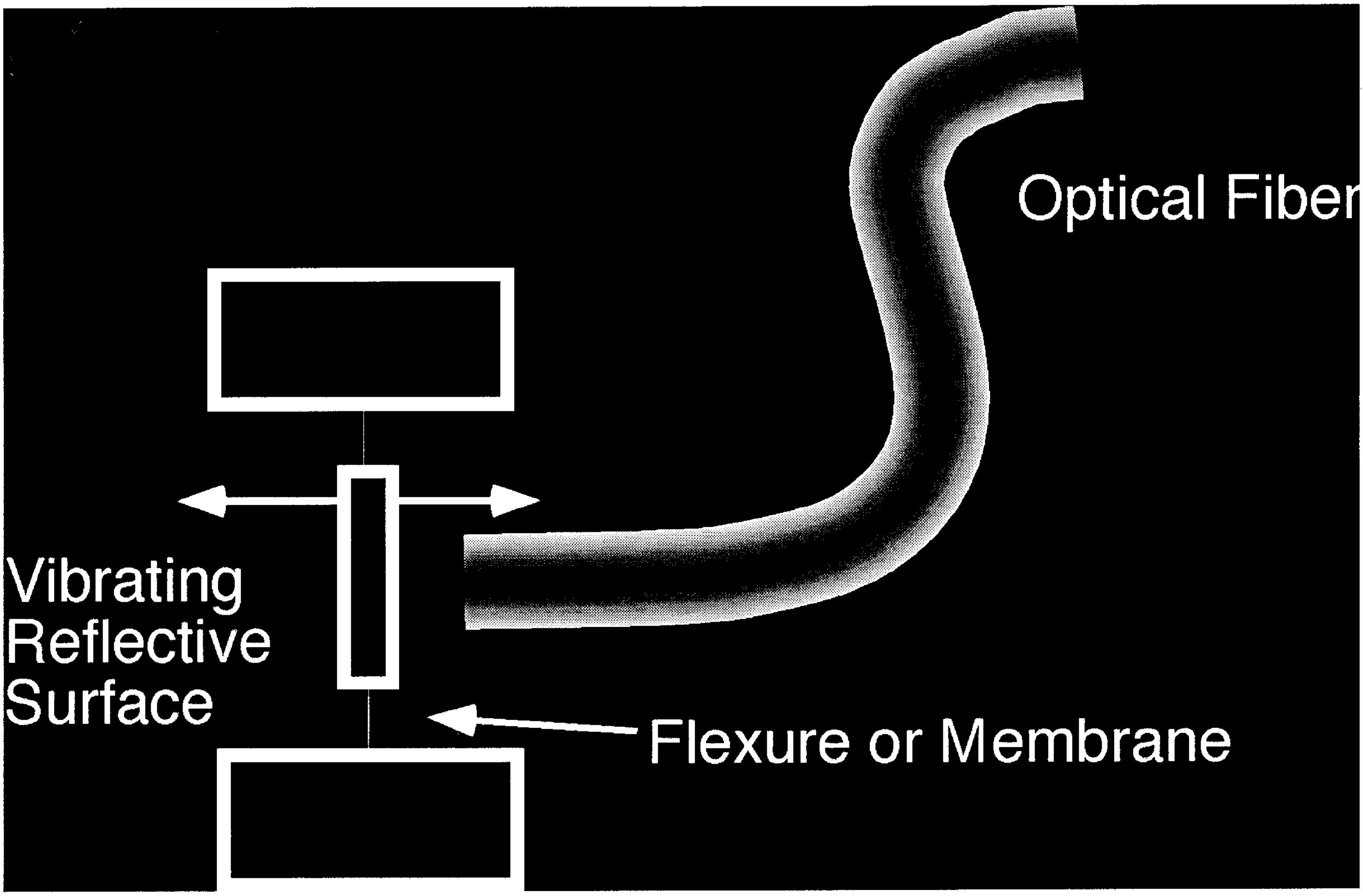

Optical Fiber
Vibrating
Reflective
Surface
Flexure or Membrane

Figure 1

MOMS Figure 1 Caption:

A simplified MOMS sensor using a reflecting surface on a flexible mount or membrane and the end face of an optical fiber to form an optical interferometer that can sense vibration. The vibration of the flexible membrane allows the reflecting surface to move, changing the resonance wavelength of the interferometer, modulating the intensity of the light that is reflected back into the interferometer. At the other end of the interferometer is a light source and a detector.

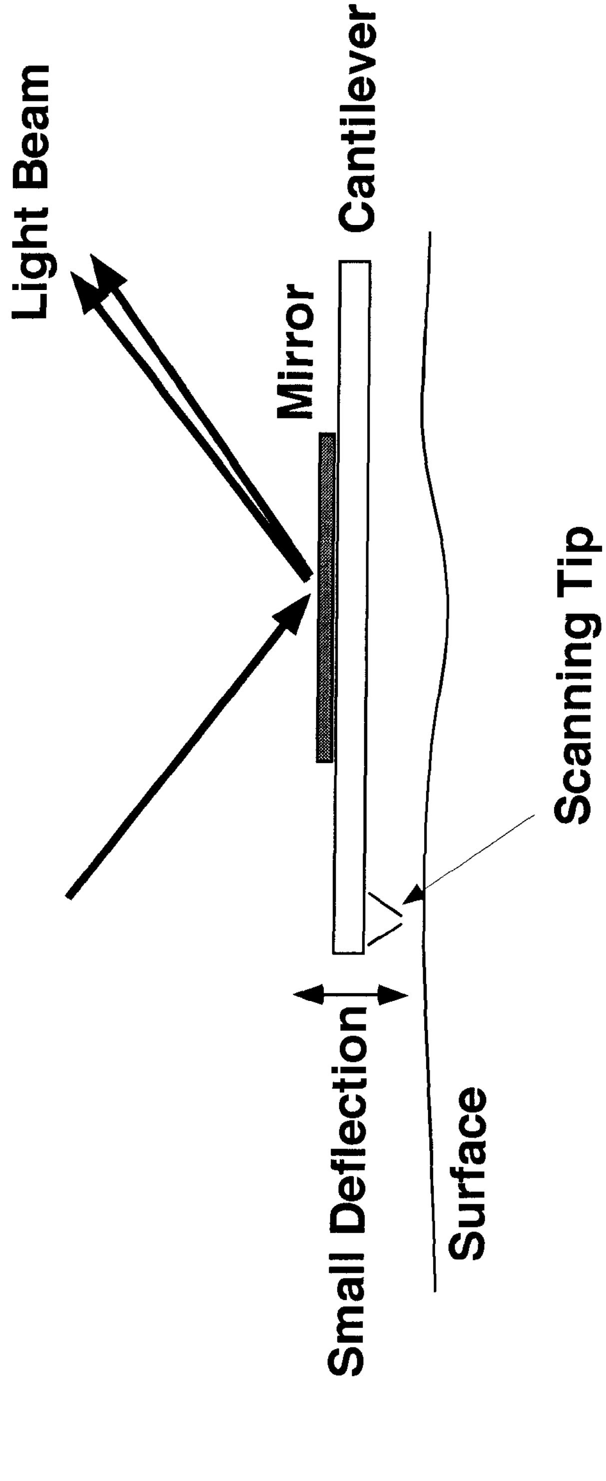
Light Beam
Cantilever
Mirror
Scanning Tip
Small Deflection
Surface

Figure 2

MOMS Figure 2 Caption:

A simplified representation of how a light beam is used to sense minute deflections of a micromachined cantilever in an atomic force microscope. The sharp tip is scanned very close to a surface. The interatomic forces on the tip deflect the cantilever. The light beam reflected off of the top of the cantilever amplify the motion. This MOMS device can resolve individual atoms on the surface.